arXiv:hep-ph/0402036v1 3 Feb 2004

ELECTROWEAK CONSTRAINTS
ON
LITTLE HIGGS MODELS*

PATRICK MEADE

F.R. Newman Laboratory for Elementary-Particle Physics
Cornell University
Ithaca, NY 14853 USA
E-mail: meade@mail.lepp.cornell.edu

In this talk I will give a brief introduction to Little Higgs models in general, including an overview of all models in existence thus far. I then review some of the generic constraints on these models from electroweak precision measurements.

1. Motivation for Little Higgs

The Standard Model (SM) of particle physics is an incredibly good effective field theory for particle physics below an energy of around a TeV. However, the Higgs mass in the SM is quadratically sensitive to the cutoff of the SM. This sensitivity manifests itself through loop contributions to the Higgs mass involving the top quark, gauge bosons, and the Higgs itself. Experimental evidence indicates that a light Higgs is preferred so something must be done to obtain a light Higgs mass despite these quadratic divergences. The contribution to the Higgs mass can be written as

$$m_h^2 = m_0^2 - \mathcal{O}(1)\Lambda^2, \tag{1}$$

where m_h is the Higgs mass, m_0 is the bare mass and, and Λ is the cutoff of the SM. If one desires a light Higgs mass of a few hundred GeV, then if the cutoff of the SM is much higher than a TeV one has to significantly fine tune the bare Higgs mass against the quadratically divergent contributions. Another approach to getting a light Higgs is to cancel the quadratic divergences with physics beyond the SM. Until recently the only type of physics

---

*Talk presented at *SUSY 2003: Supersymmetry in the Desert*, held at the University of Arizona, Tucson, AZ, June 5-10, 2003. To appear in the Proceedings.

2

beyond the SM that is weakly coupled and known to cancel the quadratic divergences was Supersymmetry. Recently a promising new idea has arisen called Little Higgs theories.

2. What makes a Little Higgs?

The basic idea for Little Higgs theories goes back to a much earlier idea of having the Higgs be a pseudo-Goldstone boson (PGB) [1]. If the Higgs were an exact Goldstone boson (GB) the Higgs would remain massless. However, it would only couple to other particles derivatively which is not how the Higgs must couple to SM fields. Therefore one must introduce couplings that make the Higgs a PGB so as to accommodate the structure of the SM. If one introduces these couplings naively then the radiative corrections they introduce to the Higgs mass are simply proportional to these couplings. Since the couplings in the SM such as the top Yukawa coupling are large this reintroduces a fine-tuning to the Higgs mass.

What makes a Little Higgs model is adding the crucial new ingredient of "collective symmetry breaking" [2] to the PGB idea. Collective symmetry breaking is the idea that the Higgs transforms under more than one symmetry and under each individual symmetry the Higgs is an exact GB. To break all the symmetries you need at least two couplings, therefore at 1-loop there are no quadratic divergences (they do appear at higher loop order).

Table 1.   Little Higgs models in existence thus far. The models are categorized by their global symmetries, gauge symmetries, whether or not there is a triplet Higgs, and the number of light Higgs doublets.

Global Symmetries	Gauge Symmetries	triplet	# Higgs	ref
$SU(5)/SO(5)$	$[SU(2) \times U(1)]^2$	Yes	1	[3]
$SU(3)^8/SU(3)^4$	$SU(3) \times SU(2) \times U(1)$	Yes	2	[4]
$SU(6)/Sp(6)$	$[SU(2) \times U(1)]^2$	No	2	[5]
$SU(4)^4/SU(3)^4$	$SU(4) \times U(1)$	No	2	[6]
$SO(5)^8/SO(5)^4$	$SO(5) \times SU(2) \times U(1)$	Yes	2	[7]
$SU(9)/SU(8)$	$SU(3) \times U(1)$	No	2	[8]
$SO(9)/[SO(5) \times SO(4)]$	$SU(2)^3 \times U(1)$	Yes	1	[9]

Even though there are a number of different Little Higgs models there are still some generic features that all models have in common. There is some global symmetry structure that is broken at a scale f to obtain the PGB Higgs. At around the scale f there will be new heavy gauge bosons, new heavy fermions, and some sort of heavy triplet or singlet Higgs. In

all Little Higgs models there are still logarithmic divergences to the Higgs mass from the heavy particles. Because the mass of the heavy particles is $\mathcal{O}(f)$ to avoid reintroducing fine-tuning problems the scale f needs to be around 1 TeV. Little Higgs theories become strongly coupled around a scale $\Lambda_{UV} \sim 4\pi f$ and need to be UV completed at this scale. I have listed the models in existence thus far in Table 1 to show the economy of the models, and what their generic features are.

3. Electroweak Constraints

I will now briefly discuss how we computed the Electroweak (EW) constraints on various Little Higgs models [10,11]. For the Little Higgs models we looked at we treated them as an effective field theory and integrated out the heavy particles. We then computed the tree level corrections(for the most part), to EW observables. A global fit was then performed to find a bound on the scale f. If f was required to be higher than ~ 1 TeV then the Little Higgs model in question still required a certain degree of fine tuning of the Higgs mass.
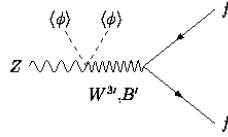

Figure 1.   Shift in Γ_z from coupling SM fermions to heavy gauge bosons.

A question one might ask is why would constraints from EW precision data be generically large? A simple example can illuminate this possibility, take for instance the generic feature of heavy gauge bosons. If the SM fermions couple to the heavy gauge bosons it can cause a modification of the coupling of a Z to two fermions as shown in Figure 1. If one assumes the mass of the heavy gauge bosons $W^{3'}$, B' to be around f and c parameterizes the strength of the coupling between the heavy and light fields then it is easy to express the shift from the SM value as

$$\frac{\delta\Gamma_Z}{\Gamma_Z} \sim 1 + c\frac{v^2}{f^2}, \qquad (2)$$

where v is the VEV of the Higgs field. Since Γ_Z is measured extremely well, it is simple to calculate that if $c \sim 1$ then the EW bound on f is

$$f > 5.13\,\text{TeV}\ \text{ to 95\% C.L.}. \qquad (3)$$

4

This bound does not mean that in all Little Higgs model $f > 5.13$TeV since it is only one shift in the EW precision data and the coupling c was artificially set to 1. However, without doing precision EW fits of the various models there is no reason a priori to believe that f is naturally around 1 TeV. We analyze several models and their variations[3,5,6] in our papers [10,11] and we find for generic regions of parameter space the bound on f is above 1 TeV which implies a certain degree of fine tuning. In most models we find some range of couplings, or a modification such that f can be a TeV. The biggest dangers for getting a large f are from mixing between heavy and SM gauge bosons, coupling of heavy $U(1)$ gauge bosons to light SM fermions, Higgs triplet VEV's (all of these may be sources of custodial $SU(2)$ violation) as well as new four-Fermi operators that are introduced or very light new $U(1)$ gauge bosons. Nevertheless since in most all models there exists a range of parameter space such that $f \sim 1$ TeV it is ultimately dependent on the UV completion of the model to tell us if that range is natural.

Acknowledgments

References

1. H. Georgi and A. Pais, Phys. Rev. D **10**, 539 (1974). H. Georgi and A. Pais, Phys. Rev. D **12**, 508 (1975).
2. N. Arkani-Hamed, A. G. Cohen and H. Georgi, Phys. Lett. B **513**, 232 (2001).
3. N. Arkani-Hamed, A. G. Cohen, E. Katz and A. E. Nelson, JHEP **0207**, 034 (2002).
4. N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, T. Gregoire and J. G. Wacker, JHEP **0208**, 021 (2002).
5. I. Low, W. Skiba and D. Smith, Phys. Rev. D **66**, 072001 (2002).
6. D. E. Kaplan and M. Schmaltz, JHEP **0310**, 039 (2003).
7. S. Chang and J. G. Wacker, arXiv:hep-ph/0303001.
8. W. Skiba and J. Terning, Phys. Rev. D **68**, 075001 (2003).
9. S. Chang, JHEP **0312**, 057 (2003).
10. C. Csaki, J. Hubisz, G. D. Kribs, P. Meade and J. Terning, Phys. Rev. D **67**, 115002 (2003).
11. C. Csaki, J. Hubisz, G. D. Kribs, P. Meade and J. Terning, Phys. Rev. D **68**, 035009 (2003).